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Hadron Absorber MARS Studies

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1 Introduction

A number of parameters characterizing the radiation in and around the Hadron Absorber cavern can be predicted before assembling the absorber and turning on the neutrino beam. MARS, a Monte Carlo program written and maintained by Nikolai Mokhov, is useful for the determination of many of these parameters. The parameters to determine include star density in the rock surrounding the absorber (to get a groundwater radiation estimate), activation of the coolant water, residual rates, air activation, and a source term at the access labyrinth. This report examines the method and results for the first two parameters, and discusses how the others might be determined by modifying and running versions of MARS14 stored in the CVS repository at FNAL.

2 Two-Stage Method with subroutine LEAK

Input file MARS.INP has a switch called INDX 6. For deep penetration problems, the user may wish to use a mathematical expectation method for transported particles. This study needs to consider deep penetration, but only for particles that reach the absorber. The first 730 meters of the geometry do not need this switch set to true, and setting it to false cuts the running time drastically. Running INDX 6=F for the part of the geometry up to the z=72968 cm plane determines a source term for that plane. In a second run, using INDX 6=T, the source term can be injected into the absorber. This method approximately quarters the running time on the first run through. Subsequent runs are even faster since this study focuses on the absorber, and the first 730 meters do not need to be run again.

2.1 leak1

After progressing through the target and decay pipe regions, which were defined by Catherine James[1], an "if" statement makes zonenum = -1 for all $z < 72968cm$. When particles reach zone -1, MARS calls subroutine leak, and the following lines of code print information about the particle to a file.

```
Zout = Z - 72968.0D0
IF (Zout.ge.0) THEN
WRITE(9,201) JJ,W,E,X,Y,Zout,DCX,DCY,DCZ,TOFF
```

[1] Daniel Fabrycky's only contribution was to remove the hadronic hose and the hose's magnetic field, which was done after the Beam Simulation Workshop II on August 24, 2001.

A file called fort.9 appears with many lines like this one:

```
 1 1.000000E+00 1.194428E+02 -252.884 69.105 0.252 -3.548097E-04
1.038763E-04 9.999999E-01 2.434025E-06
```

Each line of this file represents a particle with a statistical weight. Counting these weights reveals that non-interacting protons make up the vast majority of the energy of the beam at the end of the decay pipe. About 21% of the incident protons reach the end of the decay pipe. For a typical run of 50,000 incident protons, the fort.9 file contains about 12,400 lines, These source term files were then stored in a directory, ready to be used for multiple absorber runs.

For the first part of the two-stage method, CPU time is 0.65 seconds per incident proton on an 866 MHz machine.

2.2 leak2

The geometry for the second stage starts (z=0) where the first stage left off. Subroutine beg1 reads the source term file like so:

```
READ(9,301) JJ,W,E,X,Y,Z,DCX,DCY,DCZ,TOFF
```

With INDX 6=T, this stage yields an MTUPLE.NON file which has the desired star densities and other information.

CPU time is 0.56 second per particle on an 866 MHz machine, which is equivalent to 8 incident protons per second, not including the time it took to run leak1 initially.

3 Geometry and Zoning

The geometry of the absorber was determined from technical drawings produced by Ernie Villegas. Since early July 2001, updates were made based on emails from members of the absorber team at Fermilab, notably Alan Wehmann. The user-defined geometry for the absorber primarily resides in the subroutine absorber_alan, which includes files from the directories absorber_inc and absorber_inc_dan. In absorber_alan, MARS uses if/then blocks which use the x, y, and z positions of a particle to determine what zone and material it is travelling through. Sometimes this code has several layers of if statements, both to embed one material in another, as well as to disregard details if the particle is not in their vicinity. For the most complete example of this layering procedure, see absorber_inc_dan/elements_code_inc in mars-base on the CVS repository (see section 6).

3.1 Coordinates for the absorber

On the geometry pictures below, positive z is in the direction of the beam, x is up, and y is beam-left (west). Several times in the code the coordinates are either translation or rotated. For instance, the absorber tilts up 0.0583 radians with respect to the z-axis, which causes the feeder pipes (zone 10 in fig. 4) to disappear and reappear in a YZ slice, and the roof of the access tunnel (zone 33 in fig. 1) to slice along an angle.

3.2 Rock Zoning

The rock zones were redefined several times to encourage consistent statistics. Alan Wehmann's original definition consisted of many zones[2]. Even with high statistics[3], almost none of the zones received consistent star counts, as judged by a 20% relative error standard. To solve that problem, many of those zones were combined. Rough star density plots indicated keeping a distinction between upstream rock and downstream rock would be a good idea, since there is a large discrepancy in star density[4]. Zones 12-14 were incorporated into zone 11, and zones 26-32 were incorporated into zone 25 for the main set of runs. This change made three main rock zones: upstream, downstream, and back wall. An extra set of runs with zones 11-14 and 24-32 combined into one zone (essentially the whole cavern) was done. The results for both of those sets are in section 4.

3.3 Water Zoning

Tritium production in the RAW system is of interest. The coolant system is coded to fairly high accuracy (See fig. 5). Each aluminum console has two circuits of coolant water, fed by pipes from the back of the absorber. The feeder pipes are modeled until the back of the steel, where the star density is too low to affect the total star count. Since the water will be flowing when the beam is on, the total stars per proton matters more than the star density. In section 4 is a table of stars per proton for the two circuits. Zone 37 is the upstream loop of each pair, and is fed by beam-left pipes. Zone 38 is the downstream loop of each pair, and is fed by beam-right pipes. Inside the consoles the water flows through holes drilled in the aluminum and elsewhere it flows through aluminum piping, zone 10. See fig. 4. Although the pipes

[2]Shown in fig. 1 and fig. 2

[3]5 runs of 1.3 million events, whose results were reported at the Aug. 24, 2001 Beam Simulation Workshop II

[4]The discrepancy turned out to be a factor of 20; see star density table in section 4.

and holes are round, they are modeled with square cross sections. The cross sectional area is kept the same.

4 Results

After running MARS N times, with distinct random number seeds, a value for the star density for each zone is reported. For the ith run, call the star density a_i. For combining several runs, the Monte Carlo theory recipe is:

$$\bar{a} = \frac{1}{N}\sum_{i=1}^{N} a_i$$

$$\sigma = \sqrt{\frac{a_{sq} - \bar{a}^2}{N-1}}$$

where

$$a_{sq} = \frac{1}{N}\sum_{i=1}^{N} a_i^2$$

and the denominator $(N-1)$ is used instead of N for a relatively small number of trials $N \sim$ 5-10. Relative errors must be below 20% for this analysis. The output file MTUPLE.NON reports an error with each star density, but with this method, the errors are estimated by the sample standard deviation of 5 to 10 runs. So here the errors that MARS reported are not used, except to confirm that they are roughly the same.

Finding the average and error of 10 runs of 500,000 incident protons produces the table on the following page. The two-stage method requires renormalizing the star densities reported by the MTUPLE.NON output file. The errors reported are the sample mean's standard deviation; to get the relative error one must multiply by the square root of 10. Since zones 22 and 24 have relative errors bigger than 20%, the reported star density is not considered valid.

Zone	Material	Volume	$stars/p * cm^3$	error	% error
1	aluminum	$5.115 * 10^5$	$3.497 * 10^{-6}$	$5.9 * 10^{-9}$	0.169
2	aluminum	$5.115 * 10^5$	$7.780 * 10^{-6}$	$1.3 * 10^{-8}$	0.173
3	aluminum	$5.115 * 10^5$	$1.023 * 10^{-5}$	$2.0 * 10^{-8}$	0.199
4	aluminum	$5.115 * 10^5$	$1.072 * 10^{-5}$	$2.6 * 10^{-8}$	0.241
5	aluminum	$4.548 * 10^5$	$7.777 * 10^{-6}$	$2.3 * 10^{-8}$	0.294
6	aluminum	$5.115 * 10^5$	$8.445 * 10^{-6}$	$2.5 * 10^{-8}$	0.293
7	aluminum	$5.115 * 10^5$	$6.782 * 10^{-6}$	$2.3 * 10^{-8}$	0.336
8	aluminum	$5.115 * 10^5$	$5.223 * 10^{-6}$	$1.3 * 10^{-8}$	0.254
9	steel	$1.245 * 10^8$	$1.631 * 10^{-7}$	$3.7 * 10^{-10}$	0.225
10	aluminum	$2.780 * 10^4$	$8.018 * 10^{-7}$	$5.0 * 10^{-9}$	0.620
11	dolomite	$2.757 * 10^8$	$3.187 * 10^{-11}$	$9.4 * 10^{-13}$	2.95
15	concrete	$7.974 * 10^6$	$7.214 * 10^{-9}$	$5.2 * 10^{-11}$	0.719
16	concrete	$4.587 * 10^6$	$1.095 * 10^{-8}$	$1.1 * 10^{-10}$	1.00
17	concrete	$1.330 * 10^6$	$1.456 * 10^{-9}$	$5.0 * 10^{-11}$	3.41
18	concrete	$8.166 * 10^6$	$1.051 * 10^{-9}$	$2.6 * 10^{-11}$	2.47
19	concrete	$8.739 * 10^6$	$7.094 * 10^{-9}$	$7.3 * 10^{-11}$	1.03
20	concrete	$2.250 * 10^7$	$2.849 * 10^{-9}$	$1.8 * 10^{-11}$	0.646
21	concrete	$2.172 * 10^7$	$5.083 * 10^{-11}$	$2.2 * 10^{-12}$	4.41
22	concrete	$2.281 * 10^7$	$1.031 * 10^{-10}$	$1.3 * 10^{-11}$	12.3
24	dolomite	$3.479 * 10^8$	$1.799 * 10^{-12}$	$6.5 * 10^{-13}$	36.1
25	dolomite	$7.864 * 10^8$	$1.543 * 10^{-12}$	$1.0 * 10^{-13}$	6.50
37	water	$2.6086 * 10^4$	$2.595 * 10^{-7}$	$1.421 * 10^{-9}$	0.548
38	water	$2.5391 * 10^4$	$2.606 * 10^{-7}$	$1.070 * 10^{-9}$	0.411
66	steel	9244.	$2.733 * 10^{-5}$	$2.0 * 10^{-7}$	0.743
67	steel	9244.	$4.111 * 10^{-6}$	$7.9 * 10^{-8}$	1.91
68	aluminum	$2.834 * 10^4$	$4.893 * 10^{-5}$	$2.8 * 10^{-7}$	0.569
69	aluminum	$2.834 * 10^4$	$5.872 * 10^{-6}$	$3.2 * 10^{-8}$	0.547
83	concrete	$1.992 * 10^5$	$1.961 * 10^{-9}$	$1.2 * 10^{-10}$	6.29
89	concrete	$2.178 * 10^5$	$4.531 * 10^{-9}$	$2.0 * 10^{-10}$	4.37

4.1 Water results (total stars)

Zone	$stars/p$	error	%error
37	$6.769 * 10^{-3}$	$3.7 * 10^{-5}$	0.55
38	$6.617 * 10^{-3}$	$2.7 * 10^{-5}$	0.42

4.2 Rock Results

For another 10 runs, rock zones 11, 24, and 25 were combined into one big zone, which gave the following results:

Volume	$stars/p * cm^3$	error	%error
$1.4100 * 10^9$	$7.814 * 10^{-12}$	$2.09 * 10^{-13}$	2.67
	$stars/p$	error	
	$1.10 * 10^{-2}$	$2.95 * 10^{-4}$	

5 Future Studies

As mentioned in the introduction, a few more parameters are interesting to the design of the absorber and its cavern.

5.1 Residual Radiation

Zones 60-89 have been defined to get statistics regarding residual radiation in the absorber and surrounding concrete. Most of the zones get too few statistics to satisfy the 20% benchmark for relative errors. A few zones passed that standard and are included in the star density table on the previous page. Unfortunately, they were mostly on the inside of the absorber, where the values do not matter unless repairs are needed. The interesting zones for residual radiation are on the outside of the absorber, where workers may be. When someone decides to examine this problem, he or she will most likely need to modify the "rr" include files in the absorber_inc directory.

5.2 Labyrinth Source Term

This problem has not been studied much. For the leak2-absr2 version in the CVS repository, the access tunnel was defined as a blackhole zone with zonenum=-2. Just as the leak subroutine in "leak1" wrote a source term file, the leak subroutine records the information of particles breaching that zone. At first glance, it appears that statistics concerning the access tunnel will be difficult to gather. On a test of 5 million incident protons, summing the weights the particles which reached that zone yielded only 89. When this problem is addressed directly, the details of the absorber (ie, water system, residual radiation zones) and details of the upstream concrete should be deleted to reduce the computing time.

5.3 Air Activation

Study has not begun on air activation. It would be an interesting direction to go in, and since the geometry is already defined, it seems to be fairly straight-forward. It may be good to break the air into several different zones, especially in areas where it mixes only slowly with the larger mass of air.

6 CVS Repository

As of September 19, 2001, the Concurrent Versions System at Fermilab has the MARS code which was used for this document. "Leak1" then "leak2-absr2" were the versions used to get most of the output, and the results of section 4.2 took only a few simple modifications to "leak2-absr2." For future studies, it will be necessary to checkout a version of mars and update it. Before using the CVS version of mars, please read mars/README, which gives the conventions and usage instructions.

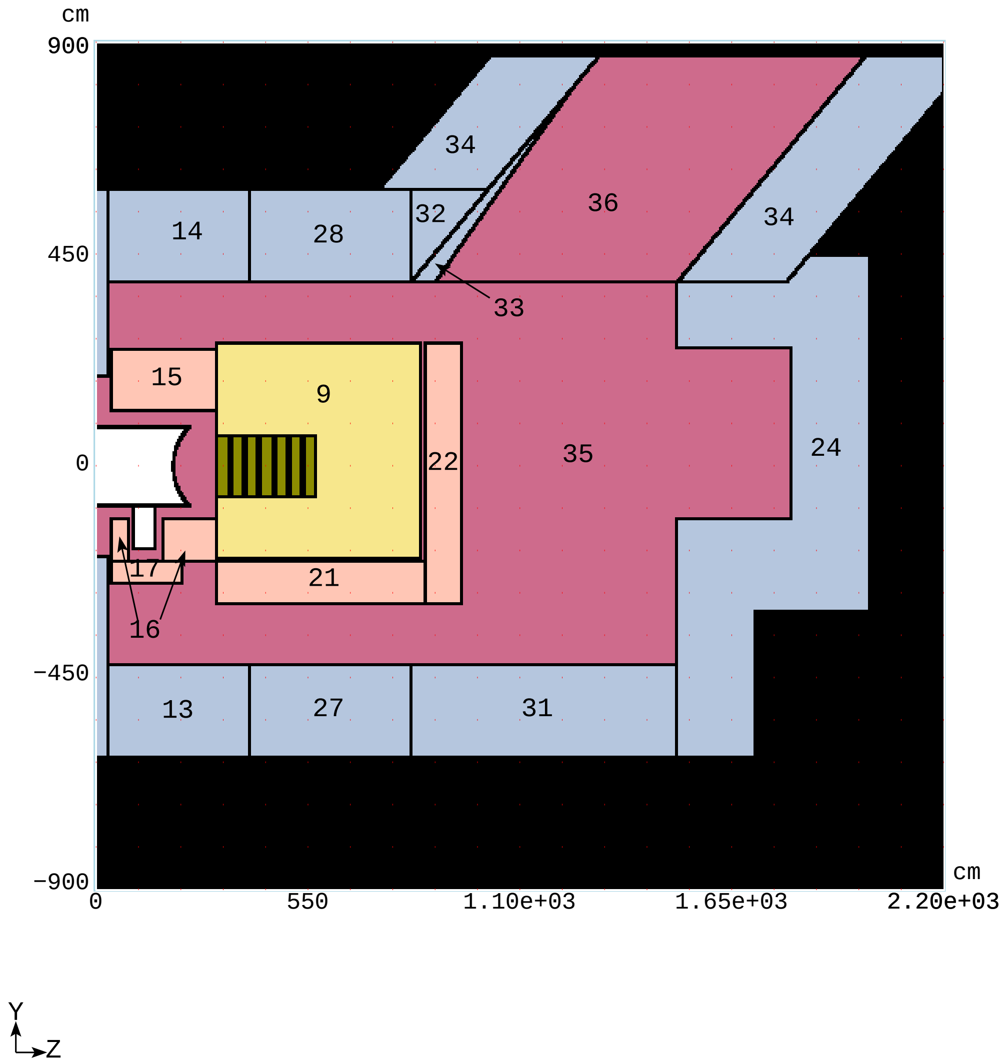

Figure 1: Zone Numbers. X=0 slice of YZ.

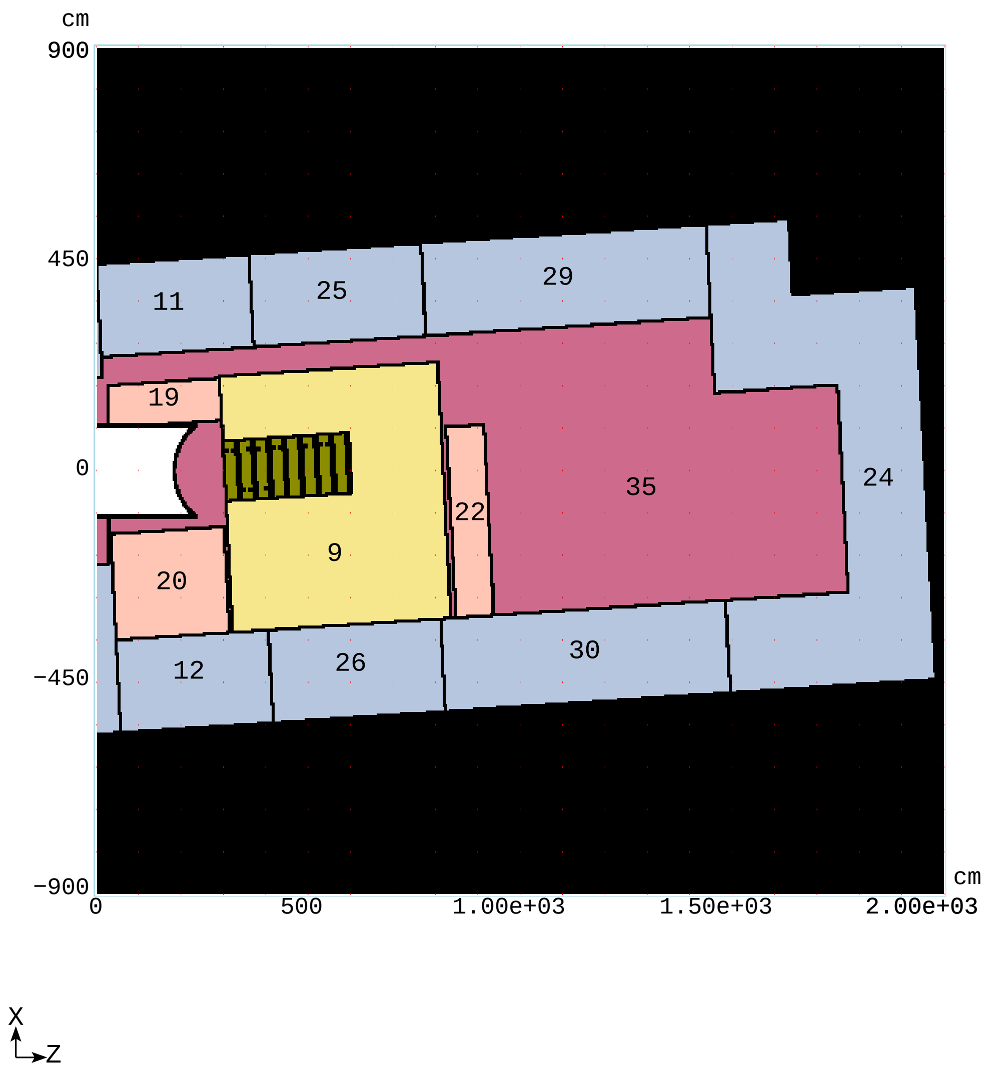

Figure 2: Zone Numbers. Y=0 slice of XZ.

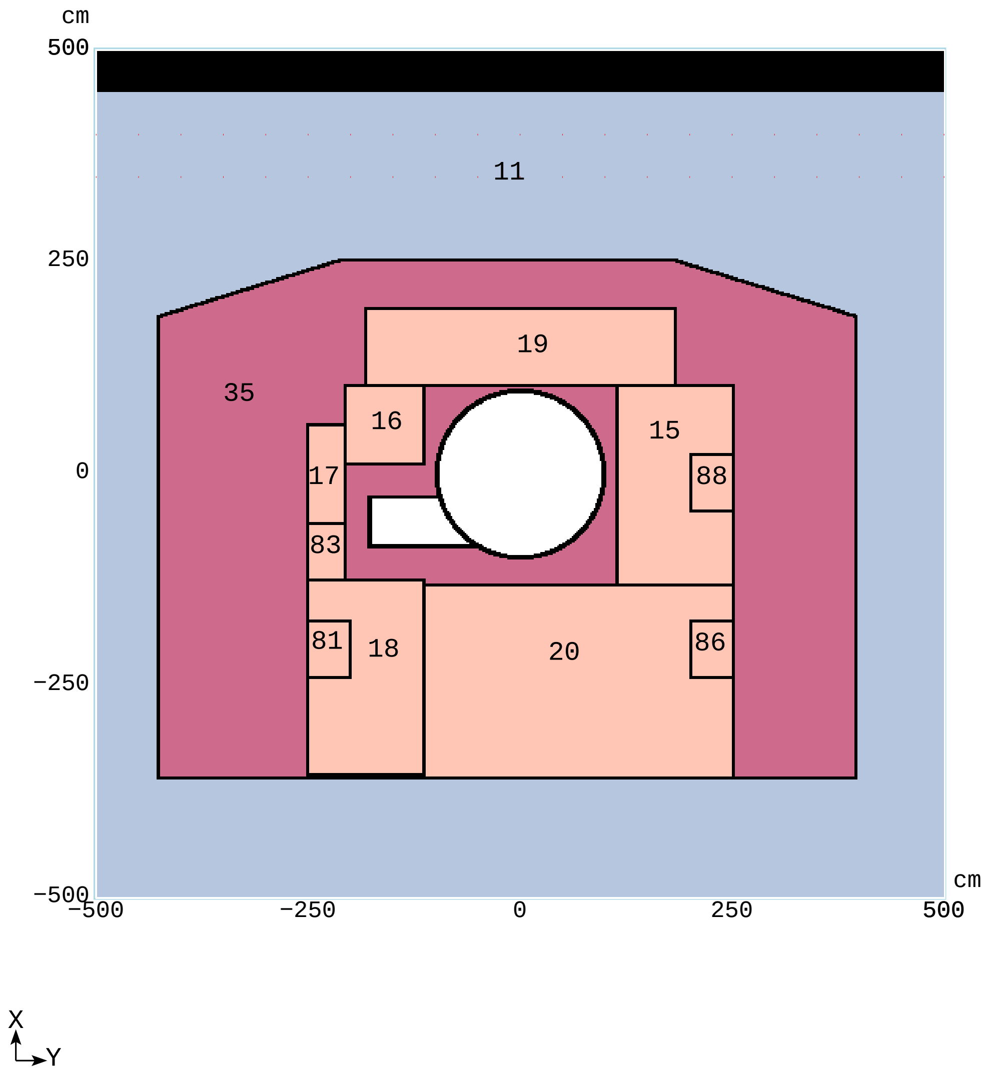

Figure 3: Upstream concrete. Z=73,100 slice of XY. The access port to the absorber is shown.

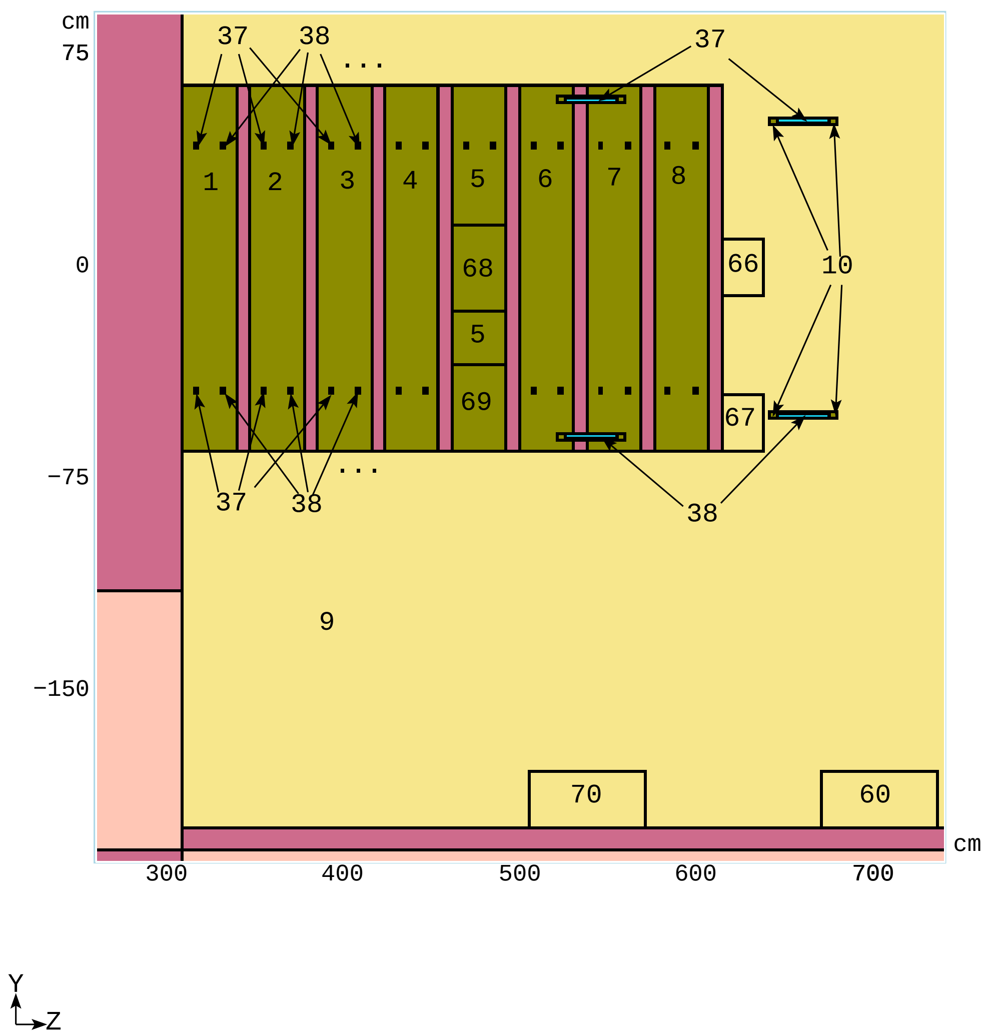

Figure 4: Details of core. X=-12 cm slice of YZ.

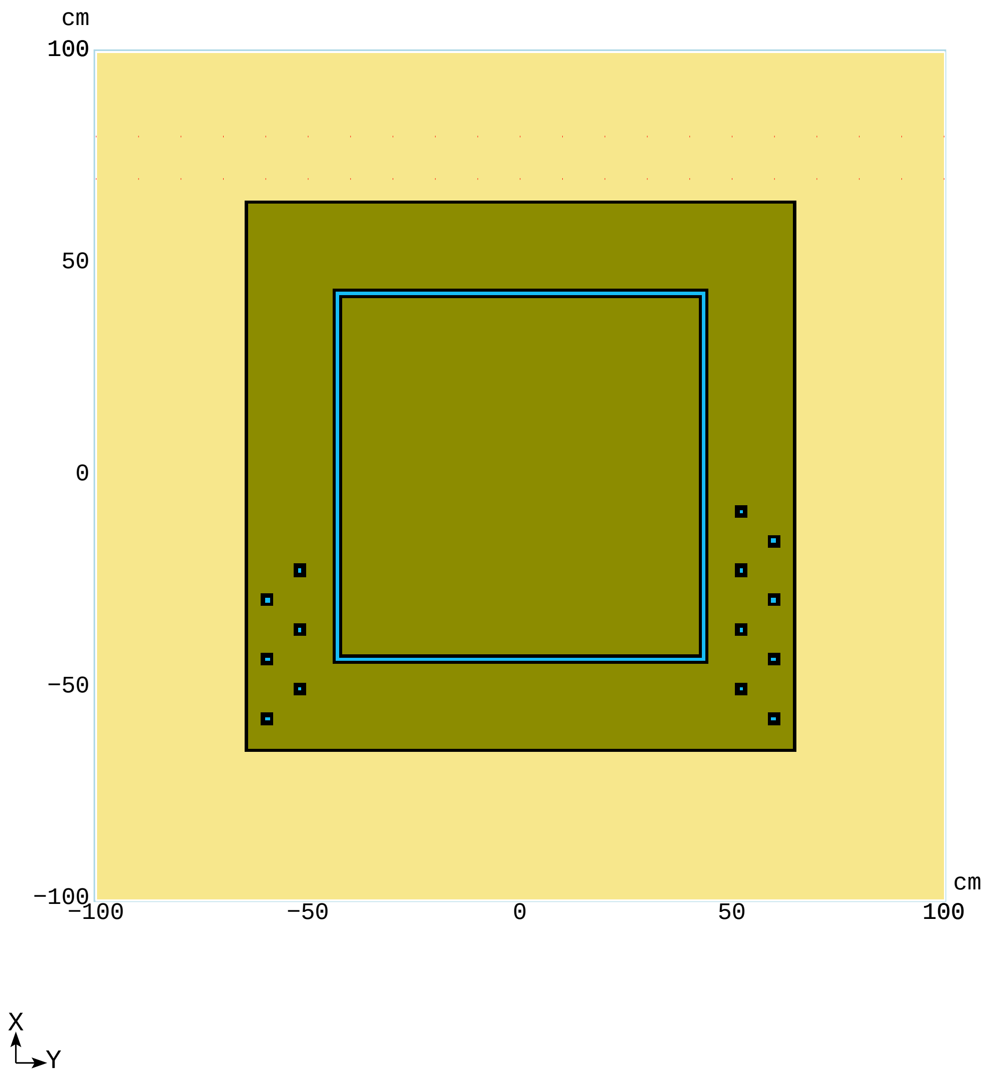

Figure 5: Coolant water system. Fourth console.

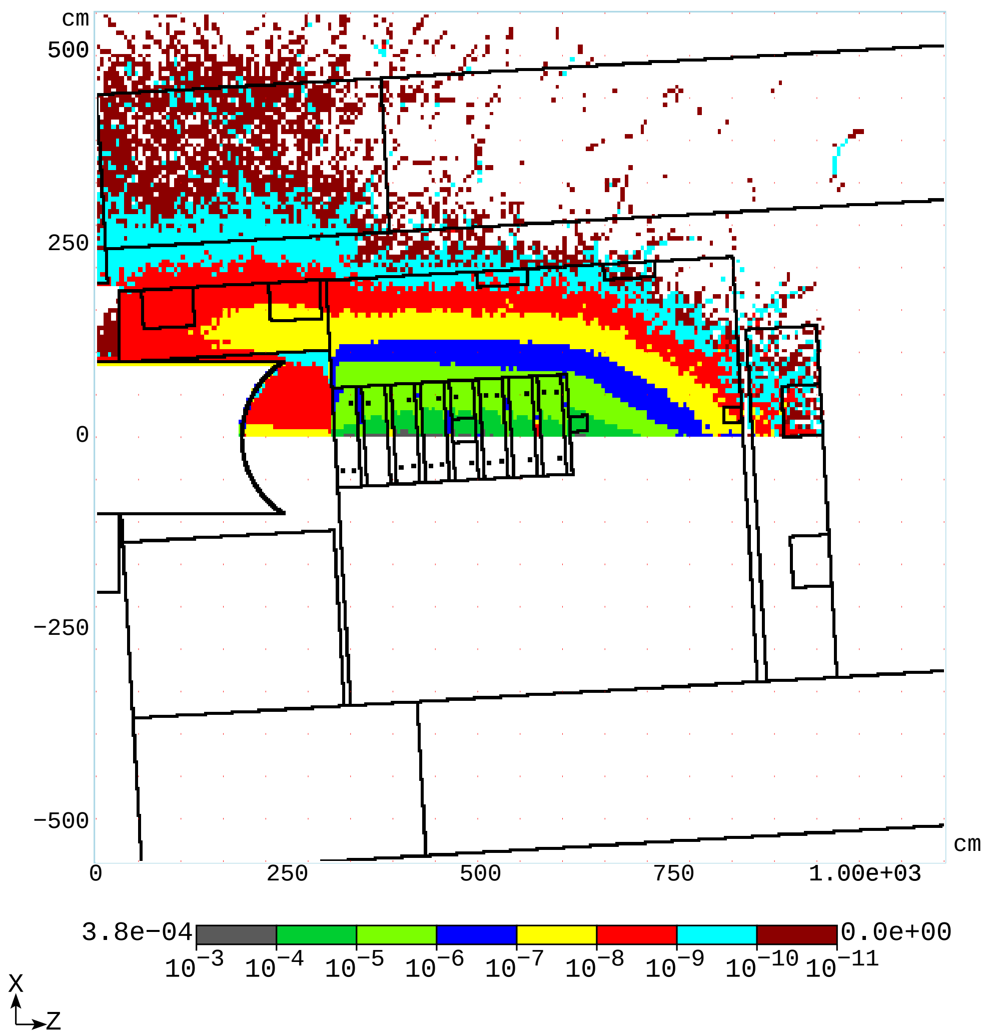

Figure 6: Star Density Plot, XZ. Best viewed in color.

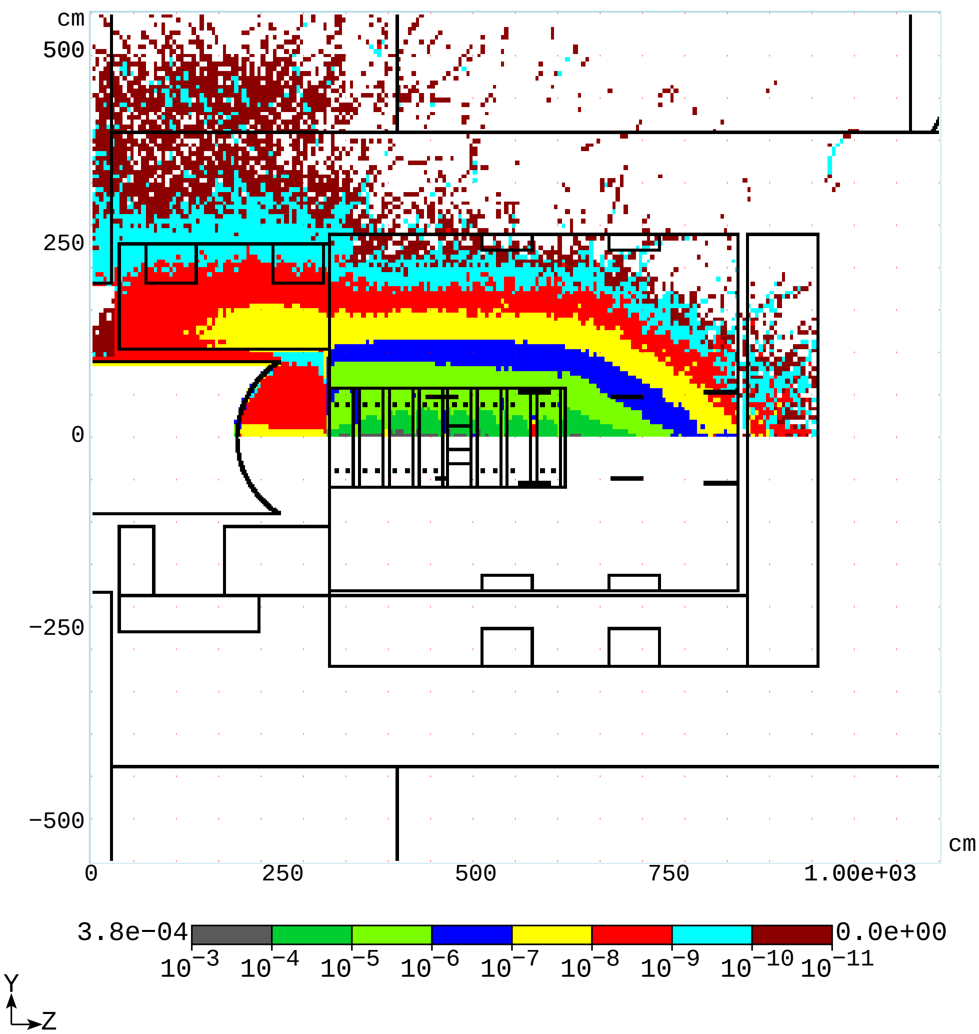

Figure 7: Star Density Plot, YZ. Best viewed in color.